National Defense Center for Energy and Environment

# Determination and Validation of Open Burn Emission Factors for JP-8 Aviation Fuel to Better Estimate Annual Emissions and to Learn the Role Pool Fire Size has in Production of Combustion Species

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# Open Burning of JP-8 Aviation Fuel

- Research, Development, Testing, and Evaluation (RTD&E) of weapon systems for the Navy and other agencies:
  - Insensitive Munitions (IM) Program developed in the wake of catastrophic losses on USS Forrestal, USS Oriskany, USS Enterprise, and USS Nimitz
  - IM Program fast cook-off testing required by law to demonstrate fleet ordnance will resist detonation when subjected to liquid pool fire conditions

*Courtesy of NAWCWD*

# Open Burning of JP-8 Aviation Fuel

- Army uses JP-8 open-burning for fire-fighting training and for permitted open-burning of some unserviceable munitions.

*Courtesy of NAWCWD*

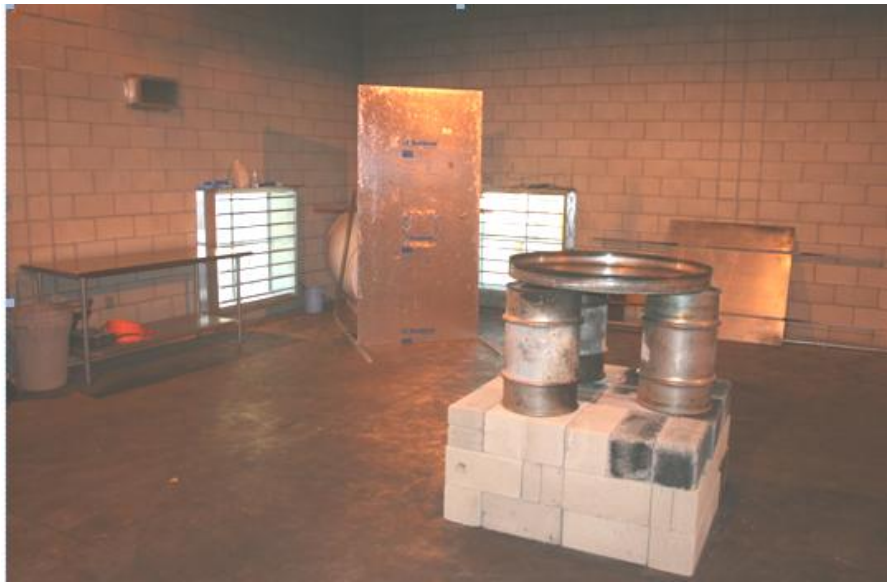
# Naval Air Warfare Center Weapons Division (NAWCWD)

- NAWCWD China Lake, CA, conducts open pool burning of JP-8 in support of the Department of Defense (DoD) RTD&E and fire training needs.
- Roughly 20,000 gallons of JP-8 is open-burned per year at NAWCWD China Lake.
- The amount of JP-8 burned in a year must reported to the local air pollution control districts and United States (U.S.) Environmental Protection Agency (EPA), along with an estimate of associated emissions.

# Quantifying JP-8 Emissions

- No suitable JP-8 emission factors exist; emissions must be estimated using methods developed for other types of sources such as boilers and orchard heaters (smudge pots).
- NAWCWD China Lake Environmental Office requested JP-8 emissions factors for controlled species.
- NAWCWD China Lake completed emission testing on a 5-$ft^2$ open pool fire of JP-8 using published U.S. EPA methods.

# NAWCWD Testing at China Lake



Burn Room With Elevated Burn Pan and Fuel Tank Behind Radiant Barrier


Sampling Ports in Scrubber Duct Atop the Burn Room

# Objectives

- Validate NAWCWD China Lake data-
  - Validation is necessary because other defense agencies that open burn fuels for testing may depend on these results in the future.
- Determine what role (if any) pool fire size might play in the production of combustion species-
  - Provides a basis for future comparison of results and future prediction of emissions from larger fires
  - Potential to enhance the Army's ability to continue critical mission tasks by identifying environmental effects of the JP-8 burning in different configurations

# Approach

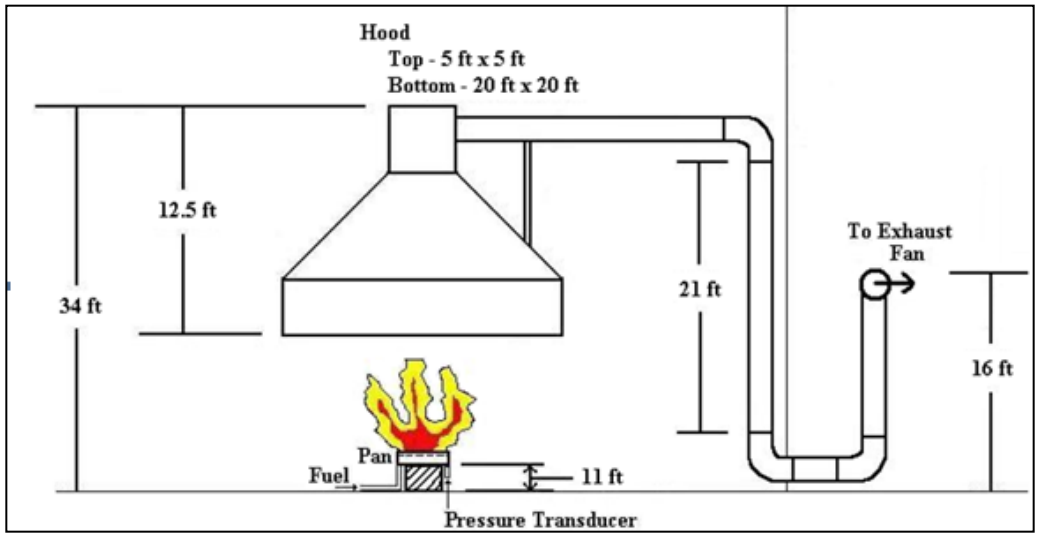
- Review NAWCWD China Lake data to determine the likelihood of reproducing data in a similarly instrumented fire
- Replicate the 5-$ft^2$ open pool fire previously accomplished at NAWCWD China Lake to verify data
- Conduct 7- and 10-$ft^2$ open pool fires to determine if pool fire size is significant in the production of combustion species

# Review of NAWCWD China Lake Data

- Confirmed issues identified by NAWCWD China Lake in the data:
  - Unreasonably high results for Carbon Dioxide ($CO_2$) and Sulfur Dioxide ($SO_2$)
  - Presence of unexpected contaminants such as Dioxin
- Reviewed issues with the test set up that may have lead to the questionable data:
  - Inaccurate, inconsistent, and corrected fuel flow rates
  - Potential for the production of contaminants unrelated to JP-8 as a result of incomplete combustion
  - Overheated Continuous Emissions Monitoring Systems (CEMS)
- Utilize lessons learned from this testing event to eliminate the identified issues and produce results with a higher degree of accuracy and reliability

# Design of Exhaust Collection System

- Determined that a 20-foot by 20-foot hood would be required to capture all emissions produced from the various size pool fires
- Designed and constructed an exhaust collection system



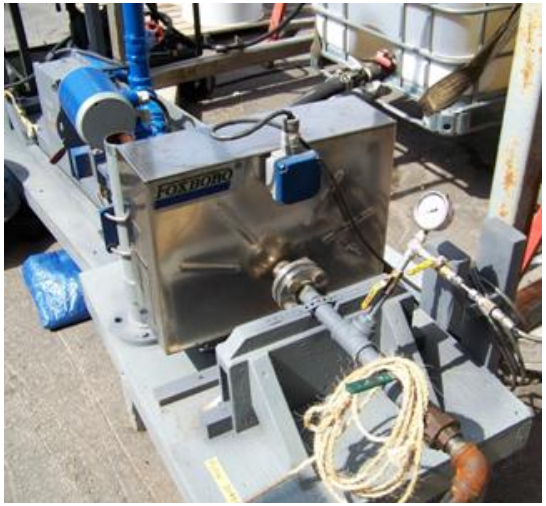

Exhaust Hood Design

Exhaust Hood as Constructed

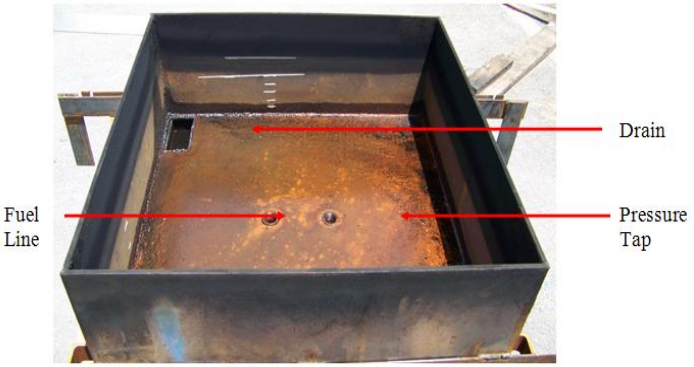
# Design of Open Pool Fire System

- Constructed open pool fire pans of 5, 7, and 10 $ft^2$ in size
- Designed a fuel delivery system to provide a consistent fuel supply as well as to track fuel consumption

JP-8 Fuel Reservoir on Load Cell




Foxboro Digital Coriolis Mass Flowmeter




Pan Constructed for Pool Fire Testing

# Open Pool Fire Emissions Testing

- Completed four individual runs for each pool fire size and collected emissions according to established U.S. EPA methods

Conducting Open Pool Fire Testing

Sampling Probes in Exhaust Duct

# Validation of NAWCWD Data for $CO_2$

- Completed three independent testing methods to obtain $CO_2$ results:
  - U.S. EPA Method 3A "Determination of Oxygen and $CO_2$ Concentrations in Emissions from Stationary Sources (Instrument Analyzer Procedure)"
  - U.S. EPA Method 3 "Gas Analysis for the Determination of Dry Molecular Weight (Fyrite Procedure)"
  - U.S. EPA Compendium Method TO-15 "Determination Of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/ Mass Spectrometry (GC/MS)

Fyrite

TO-15 Canister

# Validation of NAWCWD Data for $CO_2$ (Cont'd)

- Determined that the NAWCWD China Lake emission factor for $CO_2$ (4.09 lbs/lb of fuel) was statistically higher than what was generated in this study (3.38 lbs/lb of fuel)
- Discovered that this result of 3.38 lbs/lb of fuel was still higher than the calculated maximum $CO_2$ emission factor of 3.12 lbs/lb fuel, based on composition of the fuel
- Determined that U.S. EPA Method 3A (instrumental) may be contributing to the unexplainably high $CO_2$ emission factors; it produced higher average results when compared to Method 3 (Fyrite) and TO-15 (GC)

| | Run 1 | Run 2 | Run 3 | Run 4 | Avg |
|---|---|---|---|---|---|
| **Method 3A (instrumental)** | 3.55 | 3.08 | 3.61 | 3.27 | 3.38 |
| **Method 3 (Fyrite)** | 2.77 | ND* | 3.61 | ND* | 3.19 |
| **TO-15 (GC)** | 3.05 | 2.65 | 2.65 | 2.83 | 2.79 |

ND – No Data

* - Analysis was not performed on this run.

# Validation of NAWCWD Data

- Generated emission factors that were not statistically different (95% CI) from the NAWCWD China Lake emissions factors for:
  - Carbon Monoxide (CO)
  - Total Gaseous Nonmethane Organics (TGNMO)
  - VOCs (except Methylene Chloride and Benzene)
- Generated emission factors that were statistically lower than reported by the NAWCWD China Lake:
  - $SO_2$
  - Polycyclic Aromatic Hydrocarbons (PAHs)
  - Total Dioxin/Furans
- Generated emission factors that were statistically higher than reported by the NAWS China Lake for:
  - Nitrogen Oxide ($NO_X$)
  - Particulate Matter

# Discussion of Validation Results

- Observed decrease in $SO_2$.
  - Expected to be lower based on issues with the CEMS overheating during the NAWCWD testing
  - Results questionable based on sulfur content of the fuel
- Decrease in total PAHs.
  - Higher flow rates used during the NAWCWD testing (~16,000 Actual Cubic Feet Per Minute [ACFM]) as compared to what was used in this testing

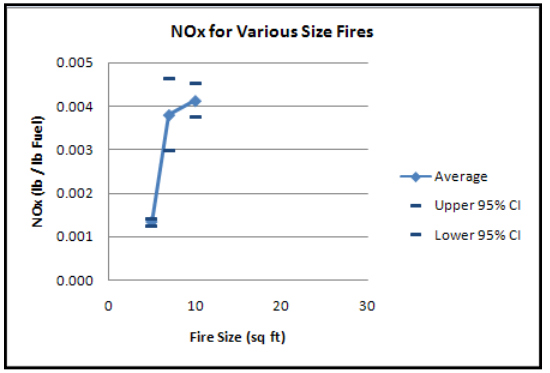
    (~ 6,000 ACFM) may have resulted in capturing PAHs from the fuel
- Decrease in Total Dioxin/Furans.
  - Expected to be lower because detection in NAWCWD testing was unexplainable
- Increase in $NO_X$.
  - Potentially due to differences in fuel composition
- Increase in Particulate Matter.
  - Higher flow rates used during the NAWCWD testing may have provided for more efficient combustion, resulting in less soot production

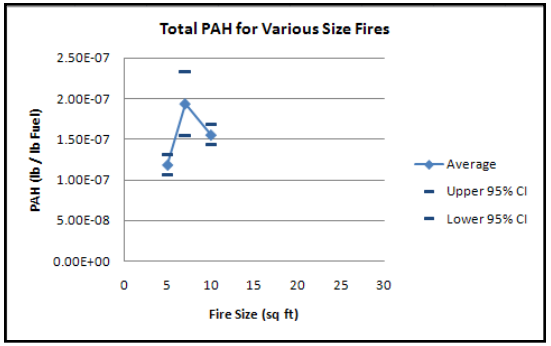
# Evaluation of Pool Fire Size

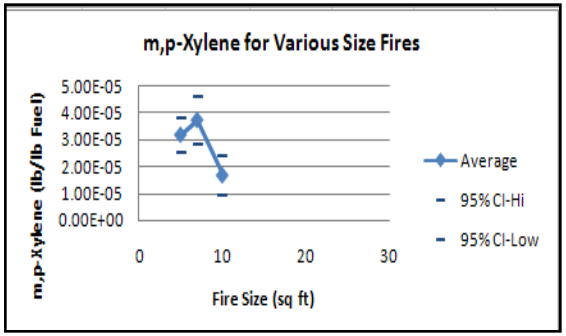
- Determined that there was not a statistically significant difference between the results obtained from the different size pool fires for the following combustion species:
  - Particulate Matter
  - $CO_2$
  - CO
  - $SO_X$
  - TGNMO
  - VOCs (Acetone, Methylene Chloride, Benzene, Toluene, Ethyl Benzene, O-Xylene,Styrene,4-Ethyl Toluene)
  - Dioxin/Furan
- Determined that there was a statistically significant difference between the results obtained from the different size pool fires for the following combustion species:
  - $NO_X$
  - m,p-xylene
  - Total PAHs

# Discussion of Results from the Evaluation of Pool Fire Size

- Discovered that the flow rate was not consistent for each fire size.
  - ~6,000 ACFM used for the 5 $ft^2$
  - ~12,000 ACFM used for the 7 $ft^2$
  - ~14,000 ACFM used for the 10 $ft^2$
- $NO_x$ and PAH results for the 5-$ft^2$ testing were found to be statistically different from the 7 and 10-$ft^2$ testing.
- m,p-Xylene result for the 10 $ft^2$ was found to be statistically different from the 5 and 7-$ft^2$ testing.



# Conclusions

- Validated NAWCWD concerns that that their results for $CO_2$ and $SO_2$ were unreasonably high
- Validated NAWCWD data for CO,TGNMO, and VOCs (except methylene chloride and benzene)
- Identified issues with accurately quantifying $CO_2$ and $SO_2$ emissions from open burning of JP-8
- Determined that the majority of the combustion species of concern (14 of 17 or ~83%) were not significantly affected by changing pool fire size
- Determined that the flow rate used to capture emissions has the potential to have a significant affect on the results
- Determined that ongoing efforts within the U.S. EPA and the DoD will have a significant impact on the submission of emission factor information to the U.S. EPA

National Defense Center for Energy and Environment

# Points of Contact

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